Army Research Laboratory

Battle Command Metric Exploration in a Simulated Combat Environment

by Janet F. O'May, Eric G. Heilman, and Barry A. Bodt

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14. ABSTRACT

Battle Command, or Command and Control, is a commander's guidance of his/her forces (command) to accomplish a goal or mission while monitoring the directed movements (control). The U.S. Army Research Laboratory's (ARL) Battlespace Decision Support Team (BDST) is exploring methods of evaluating the effectiveness of a commander's course of action (COA) and resulting battle plan. Part of our research has involved the task of identifying metrics to rate a COA. Our experiment used the One Semi-Automated Forces Testbed Baseline to iterate an ARL-developed scenario more than 200 times. We captured battlefield data supportive of COA analysis. BDST personnel used data mining techniques to extract critical elements germane to our goal of identifying variables that correctly classify battle outcome. Future applications of tools and techniques developed through this and other experiments will assist commanders as they plan asymmetric campaigns on complex terrain.

15. SUBJECT TERMS

battle command, metric, simulation

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Contents

List of Figures

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1. Introduction

Battle Command, or Command and Control (C2), is a commander's guidance for his/her forces (command) to accomplish a goal or mission while monitoring the directed movements (control). The U.S. Army Research Laboratory's Battlespace Decision Support Team (BDST) is exploring methods of evaluating the effectiveness of a commander's plan and courses of action (COAs). Part of our research involves the task of identifying nontraditional metrics to rate a COA. Battle results can be of infinite scope, but the definition of any particular battle outcome rests in a set of unique interactions. Our focus is to identify critical combat metrics through a statistical understanding of parameterized influences and interactions.

With unlimited resources, commanders could develop COAs for execution in a field exercise setting. These exercises would support data collection focused on parameters such as casualties, supply usage, and mission completion. As the exercises progressed, the unit commanders and staffs could develop improved COAs and use notional analysis tool prototypes to examine possible battle outcomes. They could then apply what they learned in the next exercise iteration. Unfortunately, unlimited resources do not exist for exercises such as these. In fact, the rising cost of field exercises has caused and will continue to cause increased military interest in combat simulation. The main factors fueling interest in military simulation are the relative low cost and the ease of battle repeatability.

BDST's experiment, the subject of this report, used combat simulations to gather data for battlefield COA evaluation. We developed a tactical scenario and executed it using the One Semi-Automated Forces (OneSAF) Testbed Baseline (OTB) version 1.0 combat simulation. Data collected for each entity/platform during scenario executions indicated the state of various battle parameters such as ammunition usage or entity damage level. When combined, these parameters form a single compound measure that we could use to classify battle outcome. Preliminary statistical analysis of experimental data suggests battle outcome classification is possible to an accuracy of 80% and that collected battlefield parameter data support nontraditional COA analysis metrics.

2. Objective

BDST places a great significance on calibrating the COA planning process using combat simulations. Specifically, we use statistically designed experimentation to collect simulation data that classify the types and meanings of various battlefield parameters. The gathering of combat simulation parameters provides the underpinnings for the construction of a C2 tool capable of showing weaknesses in proposed COAs. Combat simulation provides planning

advantages through speed of execution and accuracy of classification when gathered parameters are applied to planning combat missions.

Prior experimentation exercised OTB combat simulation capabilities incorporated by the BDST. Statistical experimental design and OTB data collection techniques have afforded us an improved understanding of OneSAF operations. Specifically, entity interaction data captured during multiple reenactments of a single combat scenario has emerged as the key to understanding the significance of nontraditional combat metrics.

Traditional combat metrics include force attrition and terrain control. Commanders traditionally make decisions and plans that govern the future of a campaign through an understanding of these conditions of battle. On today's asymmetric battlefield, soldiers face information overload and threats from unexpected directions. While traditional combat metrics are important, they represent only part of a battle's story. We propose to examine the battle for nontraditional metrics prior to and as it is being fought. Harnessing the unprecedented flow of information provided by combat simulations and real-time data feeds, we can monitor the status of nontraditional combat parameters such as individual combatant fighting status, ammunition supply, and fuel consumption. The combination of statistically significant combat parameters into nontraditional metrics gives a commander and his staff improved awareness of the battlefield from which to set the conditions for victory. Our project objectives now focus on the development of these nontraditional combat metrics, while continuing to emphasize a better understanding of simulation operations and the discovery of a method capable of depicting the battle situation at any given time.

The objective of the experiment described in this report was to determine if certain nontraditional battle parameters could assist in correctly classifying battle outcome, the hypothesis being that parameters critical to battle outcome will appear consistently throughout a set of scenario executions. We increased the number of parameters considered in the experiment to include several that are nontraditional, such as number of rounds by type used and fuel consumption.

These critical parameters may cue commanders and battle staff members to consider new, perhaps nontraditional, decision points within the planning process. For example, we want to answer questions like: if the force does not secure an objective early in the battle or if the force exhausts a certain type of ammunition, will defeat be more likely. Further, we expect that collected simulation data quantitatively reflect a planning objective's criticality. In the future, a command staff might create a branch or sequel within their battle plan to compensate for the loss of a battlefield parameter that is projected to eventually cause the loss of a mission objective, again using our projected battlefield tool. Ultimately, a real-time feed of the battle data through a future battlefield tool may provide actionable data that a commander could use to implement a deviation to a plan during battle execution.

The advantage of informed, speedy decision-making is valuable in maintaining battlefield initiative and ultimately outmaneuvering the foe. By making the enemy react to friendly forces, commanders can pick an advantageous time and place for decisive combat. Ultimately, the BDST objective is foremost to save soldiers' lives and secondarily to preserve combat power.

3. Experiment Overview

3.1 Scenario Design

The first task in the experiment was to develop a scenario that provided battlefield parameter data. The scenario had to support a computationally intense treatment of collected data. Parameter analysis required that the full spectrum of battle outcomes be possible through multiple iterations of the same initial scenario conditions. While we would have liked to use proposed futuristic equipment, such as the U.S. Army's Future Combat System, we were limited in scenario development to the combat entities already modeled in our version of OTB. Terrain was available for the region of interest, namely Middle Eastern desert with some complex terrain, such as a river and a town.

Scenario design occurred over a weeklong period exclusively using the OTB system. During that time, we ran a combined 80 repetitions of 42 distinct prototype scenario designs before building a scenario that produced a battle with varied outcomes.

As data collection and mining were paramount, we paid little attention to concerns beyond the logistical scope of a small-scale tactical battle. However, the sensitivity of the OTB simulation with regard to physical models, such as vehicle placement on terrain, weapons efficiency, armor damage capability, and operational dynamics (such as entity behavioral complexity and the randomness of free play) became apparent early in the development process. For example, the placement of a vehicle with its flank armor visible to the enemy often resulted in vehicle destruction before it could affect battle outcome in any significant manner.

The experimental scenario featured a company-sized friendly force attack on a prepared battalion-sized threat force defense. The terrain represented Southwest Asia desert typical of current conflict areas.

The friendly attack focused on a two-axis advance from the north to seize a vital crossroad located in a town to the south and behind a river obstacle. If the attacking force could occupy an objective position just south of the town, it could deny the use of the town to the enemy, disrupt communications, and, with sufficient strength, be prepared to operate behind enemy lines. Expecting an attack on the town and with time to prepare a defense, the threat forces deployed against the likely friendly force attack routes and placed their vehicles in a layered defensive line.

The attacking force organization consisted of an under-strength company equipped with M1 main battle tanks. OTB portrays the current main battle tanks (namely, the M1A1 and M1A2 tanks) as extremely potent. This OTB characteristic caused us to chose the older (and no longer in use) M1 tank to minimize the number of threat entities required to make a balanced scenario. Even using the old M1 tank models, we had to place twice the number of threat vehicles on the defense to produce an acceptable range of scenario results.

The friendly tank company consisted of 13 M1 vehicles as the attacking force. The defensive threat force was a mixture of 26 tanks and infantry fighting vehicles. See figure 1 for a list of all battle entities. The time to execute a single scenario, running in real-time, ranged from 22 to 98 min. The median time was 43 min. The use of more threat entities would increase the scenario's execution time to an unacceptable level.

Attacking Forces (by attack route):		
One Company (-)		
	East Attacker: 5 M1 Main Battle Tanks	
	West Attacker: 8 M1 Main Battle Tanks	
Defending Forces (by defending battle position):		
One Mixed Battalion (-)		
	WEST	
	Band 1:	2 T-80 Main Battle Tanks
		3 BMP-2 Infantry Fighting Vehicles
	Band 2:	2 T-72M Main Battle Tanks
		3 T-72M Main Battle Tanks
		2 T-72M Main Battle Tanks
	Band 3:	2 T-72M Main Battle Tanks
	Band 4:	2 T-80 Main Battle Tanks
	EAST	
	Band 1:	3 BMP-2 Infantry Fighting Vehicles
		2 BMP-2 Infantry Fighting Vehicles
	Band 2:	3 T-72 Main Battle Tanks
	Band 3:	1 T-80 Main Battle Tank
	Band 4:	1 T-80 Main Battle Tank

Figure 1. Scenario table of entities.

The M1 tanks were task-organized into eastern and western attack groups. The eastern attacking force would initially seize the town and then push to the railroad junction in the south. The western attack force was to initially seize the railroad bridges north of the town and then push to

the railroad junction to the south of the town. While different platoons traversed two different attack routes, the single objective unified the battle at the company level.

The defense utilized standard former Soviet Union equipment including both tanks and infantry fighting vehicles. The threat forces situated on the approach routes consisted of four progressive bands of defense designed to break up a coordinated attack on the town. Each band featured a vehicle mix designed to stop the attackers with minimal loss to the defenders. The infantry vehicles situated in the first band of defense provided long-range stopping power via their antitank missiles, while the tanks in the successive defense bands had increased firepower options for both long and close-in fighting.

Figure 2 depicts the layout of the battle. The attack represents an attempt by the friendly commander to flank the town and cause abandonment through direct fires or by controlling key terrain to the south. In actuality, the defensive posture causes this attack to be a frontal assault against a prepared defense along both attack routes. The attacker faces the worst-case scenario with an unfavorable combat power ratio. There are two defenders for every attacker and all entities are oriented favorably for the attack.

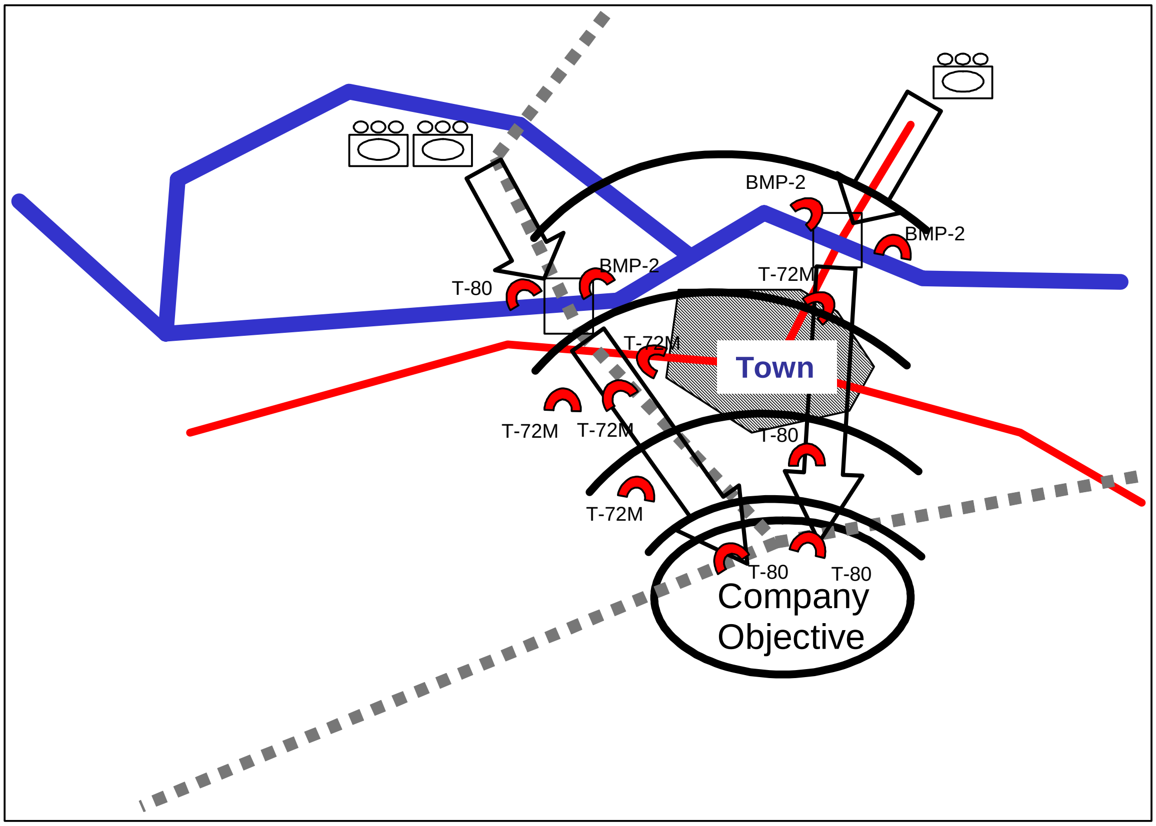

Figure 2. Battle layout.

As stated, the battle consists of two interlocking parts: the eastern battle through the town and the western battle to flank the town. While these battles are geographically spaced so that they are initially independent combats, at the latter stages, if successful, either attack force may engage defense bands three and four of the other battle. In an optimal situation for the attacker, this could occur as either force reaches the company objective. Both attacks feature an unfavorable mission for the attacker, namely a contested river crossing, early in the battle. The rest of the battle occurs on featureless flat ground with the exception of the town in the western attack.

The defense bands provide a useful metric to gage battle progress. The number of bands penetrated by the attacker was significant in determining friendly force success or failure. We also created a scoring system in which each attacking vehicle had a value of 1/4 point. (Each vehicle is worth 1/4 point so that a single friendly platoon of four vehicles equals one point.) To represent terrain control, a vehicle's total score was the number of the band penetrated multiplied by its base vehicle score. The total score for any particular scenario execution is the summation of the friendly 13 vehicle scores modified for terrain control. Further, since follow-on operational capability is important, if no attacking vehicle remained fully functional at the conclusion of a scenario execution, we then halved the entire scenario score. The victory condition for the attacking force was occupation of the objective by at least one fully functional platoon (four vehicles).

The scenario score could range from a low of zero, when the attacking force does not penetrate band 1, to a high of 13, when all attacking vehicles occupy the objective and at least one vehicle retains full functionality. Our scores in the scenario development phase ranged from a low of 1.375 to a high of 13. This ad hoc measure indicates that the scenario can provide a rich set of data highlighting the diversity of OTB behaviors and force interactions.

3.2 Execution

Following the scenario development, our next step was the actual experiment. We ran OTB on multiple systems to increase the number of executions possible in the time allotted for the experiment. All OTB scenarios ran on either Silicon Graphics, Inc. or Sun Microsystems computers. We executed the scenario 228 times over a period of three months. A central data storage repository contained the outcomes of all scenario runs for later analysis. Again, the actual time for scenario executions varied from 22 min to 98 min. The mode time for scenario execution was 41 min. BDST personnel supervised all scenario runs, ensuring accurate data collection and providing insights on battle outcomes.

3.3 Data Tabulation and Analysis

As scenario executions progressed, we began work on developing software to parse and tabulate the large amount of collected data. Central to the tabulation effort was software using the Bourne Shell Script language. The programs operated on any UNIX*-capable system.

We identified a set of 435 combat parameters for analysis (see appendix B for a listing of parameters). For the initial analysis of the data, we arbitrarily set three time slices. The time slices corresponded to times when the M1 ammunition was expended by 10% (time slice 1), 25% (time slice 2), and 40% (time slice 3). The total battle parameter set consists of three 141-parameter subsets each representing a time slice during the battle. The battle parameter data included vehicle appearance, number of rounds expended, average range for ammunition used, number of side impacts, and distance to the objective for the three M1 platoons at each time slice.

Additional parameters collected for each scenario run not tied to direct fire combat include the number of M1s occupying the objective, number of M1s undamaged, and the final score. The shell scripts collect the required fields in an American standard code for information interchange file as the starting point for multiple statistical analysis software packages. (See appendix A for a listing of Shell Scripts developed.)

4. Results and Discussion

Statistical analyses are ongoing. Initial results, however, are encouraging; we have discovered that successful classification of outcomes can occur with over 80% accuracy. Given the single response variable of battle success and data from the experiment, figure 3 shows preliminary analysis results. We are exploring different data mining techniques to extract critical battle parameters.

The Classification and Regression Tree method applied to our data produces matrices is shown on the left of figure 3. Matrix rows and columns indicate the friendly force's failure (noted as a "0") or success (noted as a "1") to achieve the scenario objective. Each cell shows the number of predictions made by our statistical analysis (columns) as compared to the actual number of observations made during the experiment (rows). The number of correctly predicted battle outcomes appears on the diagonal of each matrix. The summary information reveals that battle classification can occur quite early in the battle. We plan to apply different analysis techniques to compare the accuracy of the Classification and Regression Tree method. We will release a future report with a more detailed explanation of our experimental findings.

*UNIX is a registered trademark of The Open Group.

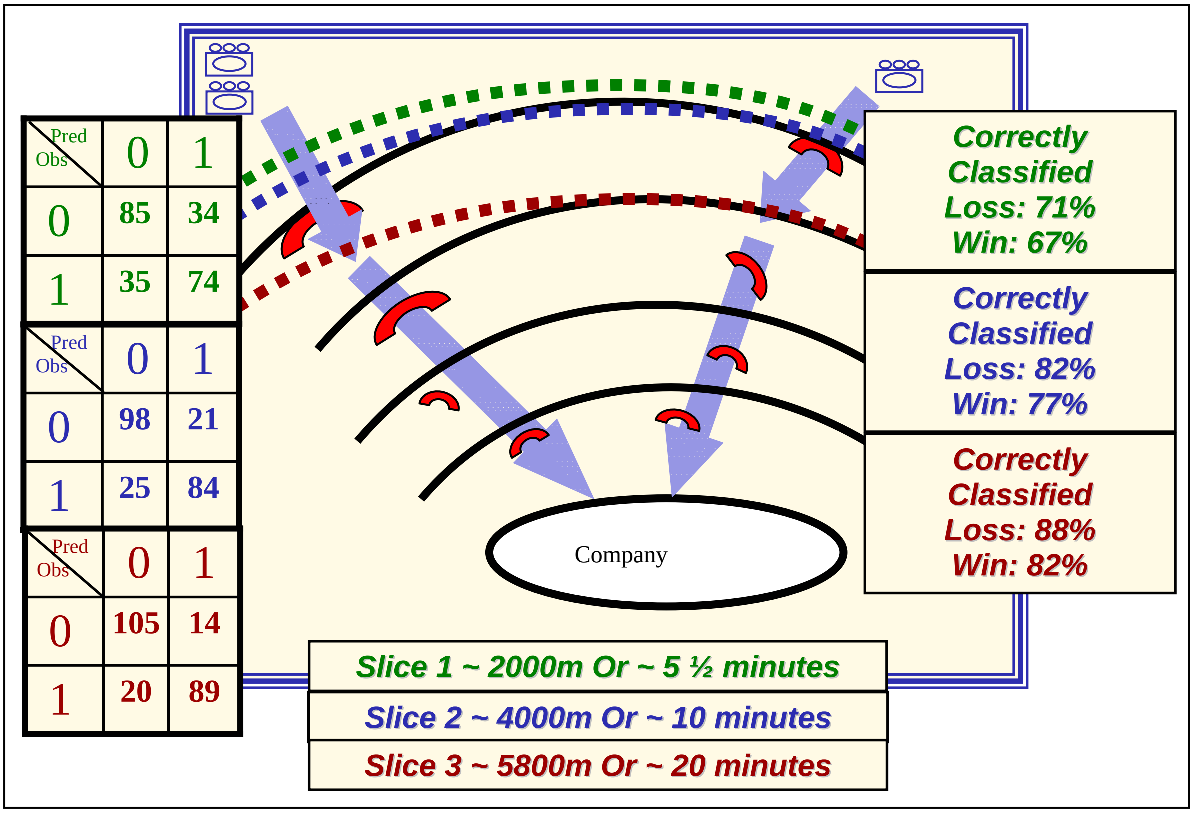

Figure 3. A battle classification summary of data from three time slices.

5. Conclusion

The BDST has launched an initial attempt to develop a tool to assist commanders in battle planning and COA monitoring. This experiment has shown that data mining techniques are useful in extracting important metrics from data collected during simulation executions. Initial experimental results show greater than 80% accuracy in classifying battle outcome. While these results occurred in the simulation realm, the concept is to apply these same techniques to future real-world mission planning and battle execution.

After the ongoing analysis of our experimental data is complete, we will concentrate on applying nontraditional metrics to conflict on urban and complex terrain. These asymmetric battlefields feature unexpected shifts in alliance and attack methods that lack conventional structure, tending toward partisan tactics and guerilla warfare. We will also attempt to locate and use combat simulations that represent these battlefields and the technologically advanced equipment projected.

The BDST is in the process of constructing our first combat planning assistance tool. This tool graphically portrays controlled areas as a function of combat power projected onto battlefield terrain. Shifts in battlefield control at the loss of specific force assets are quickly recognizable. This software tool is the first step toward a commander's automated tool suite incorporating our analysis work. When completed, the tool suite will enable commanders to plan more efficiently prior to a battle and, with direct battlefield execution data feeds, allow them to expedite the implementation of plan branches and sequels.

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Appendix A. Bourne Shell Script Descriptions

KVS2.sh This program acts as a driver for all subroutines. All subroutines are grouped into files for execution. This program is called with a directory name. The directory contains the relevant data collection file, vehicle table, and direct fire file.

cleanfile.sh Program to remove extraneous lines from the data collection file. The raw data do not contain line breaks; the first task completed is to add the line breaks. The program then removes all blank lines and creates individual files for every data collection timestamp.

parsefile.sh Program that removes data entry for entities that are not tracked. This usually means ammunition entries.

slices.sh The experiment collected data from when 10%, 25%, and 40% of the friendly ammunition was expended. These became the critical timestamps. This program determined the critical timestamps for the relevant scenario execution.

buildvt.sh The vehicle table (vt) is a separate data file that contains unique identifiers for every entity in the scenario. This program cleans up this file and removes duplicate lines.

dftab.sh This program tabulates information at each direct fire record. The direct fire file has information regarding the firer and target for every successful direct fire. The numbers of each type of ammunition used, the number of side impacts, the range of each hit, and the results of the direct fire hit are collected.

addslices.sh This program obtains information on all entities at the 10%, 25%, and 40% time slices. The following information is gathered: distance traveled from starting point, entity appearance (undamaged, mobility kill, firepower kill, mobility/firepower kill, and catastrophic kill), amount of fuel available, and ammunition available.

enddata.sh This program gathers some ending statistics: number of friendly entities on the objective, number of friendly entities undamaged on the objective, the overall score, and the computer system that ran the simulation scenario.

dfslices.sh Program that matches direct fire records from the direct fire file to the appropriate time slices determined by ammunition expenditure.

writeit.sh Program collates all the data from the previous files and then writes out 435 data values to a file called FINALFILE for each scenario execution.

Appendix B. Fields for Each Time Slice

This appendix appears in its original form, without editorial change.

Note: X corresponds to time slice number (1, 2, or 3)

Field Name	Field Description
sliceX	Slice number
elapsedtimeX	Elapsed number of seconds into scenario
pid1sX	Platoon ID
k1sX	Number of tanks in Platoon 1 (P1) that are K (catastrophically) killed
mf1sX	Number of tanks in P1 that are MF (Mobility and Firepower) killed
f1sX	Number tanks in P1 that are F (Firepower) killed
m1sX	Number tanks in P1 that are M (Mobility) killed
fuel1sX	Fuel Level for P1
H1sX	Ammo Level for 105 HEAT for P1
S1sX	Ammo Level for 105 SABOT for P1
n125H1sX	Number hits from 125HEAT on P1
n125S1sX	Number hits from 125SABOT on P1
nG1sX	Number hits from Songster on P1
nBH1sX	Number hits from 30HE_BMP2 on P1
nBS1sX	Number hits from SABOT_BMP on P1
nP1sX	Number hits from Spandrel on P1
r125H1sX	Average Range from 125HEAT on P1
r125S1sX	Average Range from 125SABOT on P1
rG1sX	Average Range from Songster on P1
rBH1sX	Average Range from 30HE_BMP2 on P1
rBS1sX	Average Range from 30SABOT_BMP2 on P1
rP1sX	Average Range from Spandrel on P1
nD25H1sX	Number side hits by 125HEAT on P1
nD25S1sX	Number side hits by 125SABOT on P1
nDG1sX	Number side hits by Songster on P1
nDBH1sX	Number side hits by BMPHE on P1
nDBS1sX	Number side hits by BMPSABOT on P1
nDP1sX	Number side hits by Spandrel on P1
n05HB1sX	Number hits 105HEAT on BMP by P1
n05SB1sX	Number hits 105SABOT on BMP by P1
r05HB1sX	Average Range 105HEAT on BMP by P1
r05SB1sX	Average Range 105SABOT on BMP by P1
D05HB1sX	Number side hits 105HEAT BMP by P1
D05SB1sX	Number side hits 105SABOT BMP by P1
n05HT1sX	Number hits 105HEAT on T80 by P1
n05ST1sX	Number hits 105SABOT on T80 by P1
r05HT1sX	Average Range 105HEAT on T80 by P1
r05ST1sX	Average Range 105SABOT on T80 by P1
D05HT1sX	Number side hits 105HEAT T80 by P1
D05ST1sX	Number side hits 105SABOT T80 by P1
nkB1sX	Number of K Kills on BMP by P1

nmfB1sX	Number of MF Kills on BMP by P1
nfB1sX	Number of F Kills on BMP by P1
nmB1sX	Number of M Kills on BMP by P1
nkT1sX	Number of K Kills on T80 by P1
nmfT1sX	Number of MF Kills on T80 by P1
nfT1sX	Number of F Kills on T80 by P1
nmT1sX	Number of M Kills on T80 by P1
dist1sX	Distance to Objective for P1
pid2sX	Platoon ID
k2sX	Number tanks in Platoon 2 (P2) that are K'd
mf2sX	Number tanks in P2 that are MF'd
f2sX	Number tanks in P2 that are F'd
m2sX	Number tanks in P2 that are M'd
fuel2sX	Fuel Level for P2
H2sX	Ammo Level of 105 HEAT for P2
S2sX	Ammo Level of 105 SABOT for P2
n125H2sX	Number hits from 125HEAT on P2
n125S2sX	Number hits from 125SABOT on P2
nG2sX	Number hits from Songster on P2
nBH2sX	Number hits from 30HE_BMP2 on P2
nBS2sX	Number hits from SABOT_BMP on P
nP2sX	Number hits from Spandrel on P2
r125H2sX	Average Range from 125HEAT on P2
r125S2sX	Average Range from 125SABOT on P2
rG2sX	Average Range from Songster on P2
rBH2sX	Average Range from 30HE_BMP2 on P2
rBS2sX	Average Range from 30SABOT_BMP2 on P2
rP2sX	Average Range from Spandrel on P2
nD25H2sX	Number side hits by 125HEAT on P2
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nDG2sX	Number side hits by Songster on P2
nDBH2sX	Number side hits by BMPHE on P2
nDBS2sX	Number side hits by BMPSABOT on P2
nDP2sX	Number side hits by Spandrel on P2
n05HB2sX	Number hits 105HEAT on BMP by P2
n05SB2sX	Number hits 105SABOT on BMP by P2
r05HB2sX	Average Range 105HEAT on BMP by P2
r05SB2sX	Average Range 105SABOT on BMP by P2
D05HB2sX	Number side hits 105HEAT BMP by P2
D05SB2sX	Number side hits 105SABOT BMP by P2
n05HT2sX	Number hits 105HEAT on T80 by P2
n05ST2sX	Number hits 105SABOT on T80 by P2
r05HT2sX	Average Range 105HEAT on T80 by P2
r05ST2sX	Average Range 105SABOT on T80 by P2
D05HT2sX	Number side hits 105HEAT on T80 by P2
D05ST2sX	Number side hits 105SABOT on T80 by P2

nkB2sX	Number of K Kills on BMP by P2
nmfB2sX	Number of MF Kills on BMP by P2
nfB2sX	Number of F Kills on BMP by P2
nmB2sX	Number of M Kills on BMP by P2
nkT2sX	Number of K Kills on T80 by P2
nmfT2sX	Number of MF Kills on T80 by P2
nfT2sX	Number of F Kills on T80 by P2
nmT2sX	Number of M Kills on T80 by P2
dist2sX	Distance to Objective for P2
pid3sX	Platoon ID
k3sX	Number tanks in P3 that are K'd
mf3sX	Number tanks in P3 that are MF'd
f3sX	Number tanks in P3 that are F'd
m3sX	Number tanks in P3 that are M'd
fuel3sX	Fuel Level for P3
H3sX	Ammo Level of 105 HEAT for P3
S3sX	Ammo Level of 105 SABOT for P3
n125H3sX	Number hits from 125HEAT on P3
n125S3sX	Number hits from 125SABOT on P3
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nDBS3sX	Number side hits by BMPSABOT on P3
nDP3sX	Number side hits by Spandrel on P3
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n05SB3sX	Number hits 105SABOT on BMP by P3
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r05SB3sX	Average Range 105SABOT on BMP by P3
D05HB3sX	Number side hits 105HEAT BMP by P3
D05SB3sX	Number side hits 105SABOT BMP by P3
n05HT3sX	Number hits 105HEAT on T80 by P3
n05ST3sX	Number hits 105SABOT on T80 by P3
r05HT3sX	Average Range 105HEAT on T80 by P3
r05ST3sX	Average Range 105SABOT on T80 by P3
D05HT3sX	Number side hits 105HEAT T80 by P3

D05ST3sX	Number side hits 105SABOT T80 by P3
nkB3sX	Number of K Kills on BMP by P3
nmfB3sX	Number of MF Kills on BMP by P3
nfB3sX	Number of F Kills on BMP by P3
nmB3sX	Number of M Kills on BMP by P3
nkT3sX	Number of K Kills on T80 by P3
nmfT3sX	Number of MF Kills on T80 by P3
nfT3sX	Number of F Kills on T80 by P3
nmT3sX	Number of M Kills on T80 by P3
dist3sX	Distance to Objective for P3

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List of Symbols, Abbreviations, and Acronyms

BDST	Battlespace Decision Support Team
C2	Command and Control
COA	Course of action
OneSAF	One Semi-Automated Forces
OTB	OneSAF Testbed Baseline

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